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Local-Rapid Evaluation of Atmospheric Conditions (L-REAC)

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ABSTRACT

In a chemical/biological attack or accident, installation commanders, Emergency Operations Centers, and first responders need immediate knowledge of local wind and other meteorological conditions at the fine scales appropriate to the emergency. Therefore, the U.S. Army Research Laboratory (ARL), Battlefield Environment Division has proposed developing a Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) System. The objective networking design for the L-REAC system will use real-time networked meteorological sensors placed at optimum locations. These data will be input in near real-time to the fastest running version available of the ARL Three Dimensional Wind Field (3DWF) model or similar urban wind field model. Continuous running updates on a server will produce a detailed picture of wind flow over the local installation available 24/7 to all forms of browser-based access such as mobile blackberry browser. In 2006, the ARL presented data at an International Test and Evaluation Association conference which verified millimeter-scaled airflow patterns observed in the 1994 Snyder and Lawson National Oceanic and Atmospheric Administration (NOAA)/Environmental Protection Agency (EPA) Wind Tunnel study with tens-of-meter-scaled measurements sampled around a full-sized building. In 2007, this ARL urban airflow research pursued an even greater spatially and temporarily detailed investigation of the urban environment around individual buildings. From this 2007 field study, the L-REAC concept was generated. This paper will present the L-REAC system and an overview of the experimental test and evaluation of features for the model to simulate urban wind flow.

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1. Introduction – The L-REAC System

On February 22, 2007, a toxic gas was released in a Baghdad neighborhood (CNN, 2007). Seventy persons were hospitalized with respiratory problems caused by the noxious gas. This event was not the first time the deadly and debilitating chlorine gas had been used in a public environment. If a similar chlorine release occurred in the United States, would there be accurate enough atmospheric information and decision making tools available for authorities to immediately respond to such a terrorist attack?

Putting the February 22, 2007 event in a military Force Protection context, a fixed installation Garrison Commander, a forward area Base Commander, or an Emergency Operations Officer would immediately be faced with the following decisions: How will I route my first responders into the hazardous area? What areas will I block off and notify occupants to Shelter-in-Place? What areas have the time and ability to evacuate before the hazard reaches them? This is not the time to gather data or prepare models and simulations to be run. Rather, immediate, quick-look answers and accurate atmospheric, local scale, characterizations are needed to provide decision makers with confidence that they know the locations and people at risk.

The identification of the key hazard features in airflows around urban structures has required a significant amount of experimental data for evaluation. These data have also served to verify airflow patterns identified by physical and computer models. Therefore, the major portion of this paper describes the supporting urban wind flow experiments.

1.1 Background

The Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) system is one of the tools the U.S. Army Research Laboratory (ARL) is developing to support decision makers and first responders in an emergency. The L-REAC System is an integrated meteorological package that monitors atmospheric airflow 24/7, evaluates atmospheric conditions in urban and complex terrain, and displays an atmospheric assessment of the “least hazardous” areas of airborne substances for first responders. While the general idea is not new, what is unique to the L-REAC concept is the ability to evaluate building-scales for a timely, detailed airflow assessment around and over urban terrain and even individual buildings if needed. This 24/7 monitoring, evaluation, and display tool is aimed at producing installation scale diagnostic air flow continuously (24/7), and allowing the decision maker to quickly zoom in to an area of interest to produce chemical/biological (CB) hazard footprint forecasts within 3–5 minutes of the hazard event’s recognition.

ARL has been researching various aspects of airborne hazardous release scenarios. Since 2000, we have been specifically researching the characteristics of airflow and stability within an urban environment. These two atmospheric parameters were selected based on their significant impact on airborne CB releases. For example, if one knows the local airflow at the time of a CB release, the direction of propagation for a toxic plume can be determined. When the stability conditions over the release site are known, the CB concentration within a toxic cloud can be ascertained.

Three progressively more intricate ARL field studies have quantitatively detailed the urban airflow and stability conditions within small building complexes. As part of the latest field study, disaster response drills were conducted concurrently with the data acquisition period. While an elaboration on each drill is beyond the scope of this paper, what we gleaned from

the experience was the value of having current, local-weather intelligence for assessing and making informed, actionable responses regarding an airborne threat to the workforce. Based on these observations, the L-REAC system concept was initiated. The L-REAC system design centers around three modules, with a network element linking the modules together into a single system. Section 1.2 will briefly describe the system design and each of the major elements.

1.2 L-REAC System and Modules

The three modules of the L-REAC system consist of a sensor module, a model module, and a public communications module (figure 1). The modular design was selected to ensure the system's ability to keep current with contemporary technology. Modularity also provides the flexibility for integrating already available resources; thus, making the system more economically sound. The next three subsections will briefly describe each major L-REAC system element.

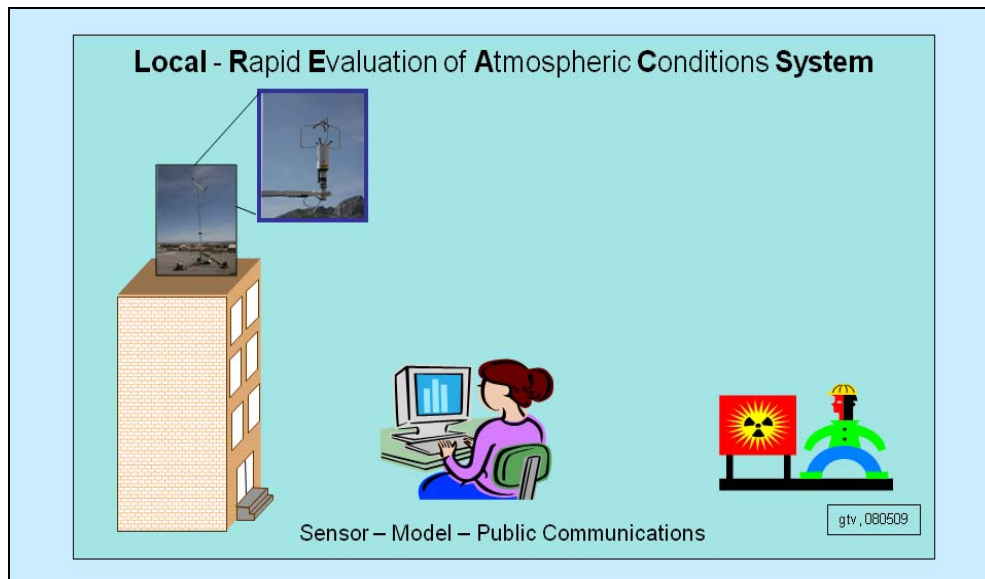


Figure 1. The L-REAC system.

1.2.1 The Sensor Module

The selection and placement of meteorological and CB-sniffing sensors were determined through the use of ARL's urban field study experience, analysis with the ARL Three-Dimensional Wind Field (3DWF) model, physical models of urban flow in wind tunnels, as well as articles from professional urban meteorological journals. The need to maintain a visual sensor for persons who are not able to access the L-REAC system output display was also integrated into the sensor selection. The specific sensors utilized began with the standard meteorological variables and were re-fined as a function of the data timeliness, availability, relevancy, and the various model requirements.

1.2.2 The Model Module

The models selected for the L-REAC System answer two primary questions:

- (1) What is the current airflow or wind field, and
- (2) What is the projected toxic plume footprint?

ARL has been developing an airflow diagnostic model called, “Three-Dimensional Wind Field” (Wang et al, 2005). This model is currently able to generate wind fields for building-scale environments in 90–120 seconds. A second model is the Los Alamos National Laboratory’s Quick Urban and Industrial Complex (QUIC) Model (Nelson et al, 2008). Coupling these models with a certified plume model completes the first-interpretation of atmospheric conditions during an airborne CB toxic release event.

The model module also expands the area of concern into a larger scaled urban environment. The use of concurrent model runs by both the quick response and slower certified airflow and plume models, are part of the L-REAC design. As part of a service-oriented approach, continuous L-REAC services will be provided on a 24/7 basis over the area that the system monitors. Hazard simulation models will be run on demand as well.

1.2.3 The Public Communication Module and Networking Elements

The Public Communication Module is set up as an intuitive, user-friendly component that is able to access relevant data through various displays. The image shown translates the complexities of the atmospheric model into quickly discernable application.

Linking each of the modules together is a non-trivial action due to the sensitive nature of the information. We have examined several wired and wireless options for this function. Each option comes with its own set of requirements; therefore, this attribute of the design is constructed in a flexible manner.

2. The Experimental Basis for Test and Evaluation of the L-REAC Wind Flow Features Over Urban Structures

Urban atmospheric environments are continually changing. Despite this dynamic attribute, wind tunnel and computer model simulations indicate that at least seven airflow patterns can be identified around and above a single building. Figure 2 shows six of these patterns, which include fetch flow, velocity acceleration, velocity deficit, reattachment zone, cavity flow, and leeward corner eddies. The seventh pattern requires two buildings to be aligned next to each other. The air flowing between these buildings is called a “canyon flow.”

ARL has verified each of these seven urban airflow patterns through a series of field tests conducted in a life-sized urban environment (Vaucher and Cionco, 2006; Vaucher et al., 2008). In addition, a statistical characterization for each feature was constructed from the evaluation of the last test dataset. Details of the statistical analysis are published in Vaucher et al., 2008. Each field test confirmed that the time duration for any sustained urban atmospheric condition ranged from seconds to minutes. The spatial scale for urban airflow patterns ran between centimeters to tens of meters in size. Thus, when first responders make decisions in response to an urban airborne threat, meteorological data timeliness and spatial relevancy are two of the most critical attributes for evaluating the situation.

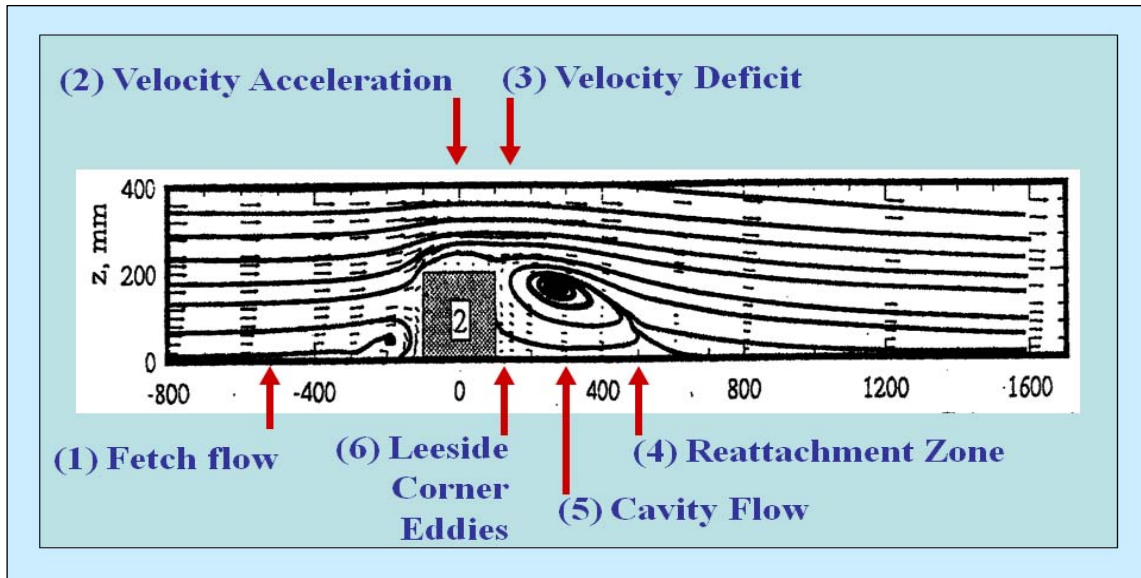


Figure 2. Airflow features around and above a single urban building (Snyder/Lawson, 1994).

All seven airflow features are relevant to the airborne toxic release response decision makers. Three airflow patterns were selected for discussion in this paper, based on their exceptional impact upon the first responder's decision making process. These patterns include: the canyon flow, the leaside corner eddies, and the (leaside) cavity flow. Each will be described in the subsequent sections.

2.1 The Canyon Flow

The canyon flow is composed of air flowing between parallel buildings. This channeled air accelerates with respect to the surrounding environment. The process whereby a fluid (air) accelerates through a narrowed pathway is also called "the Venturi effect" (Wikipedia, 2008). Using life-sized buildings, we traced airflow from the windward side of a building, through a building canyon and onto the leaside of the building (figure 3).

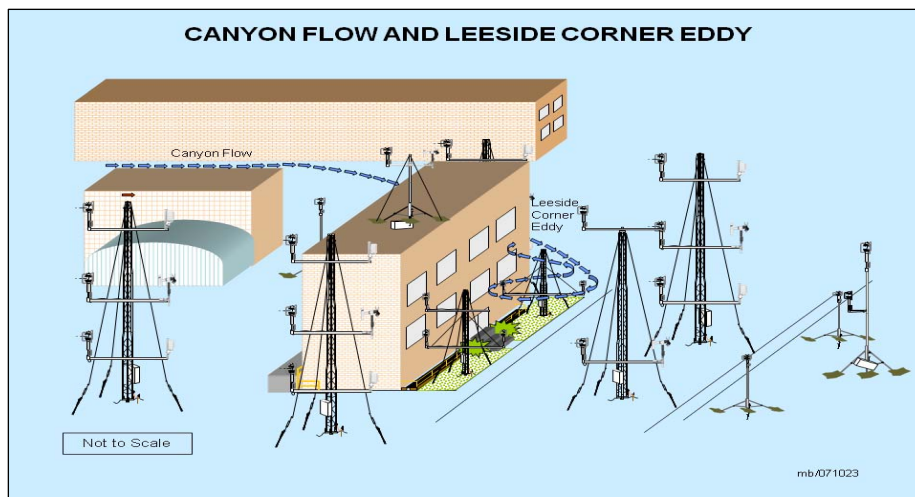


Figure 3. Canyon Flow and Leaside Corner Eddy Schematic.

In figure 4, a sample of the wind speed time series for the canyon flow is provided. Utilizing the schematic from figure 4, winds originated from the west (left of schematic) and traversed to the east (schematic right). The reference velocity (brown data) was sampled from three levels on a Fetch Tower (brown circle with red center on the schematic). The wind speeds within the canyon (green data and circle) showed a systematic velocity increase with respect to the reference velocities. Once the air exited the canyon and entered what was called the “North-Reattachment Zone” (blue data and circle), the original velocity magnitudes were resumed. The urban scenario from which these data originated held a very consistent west-northwesterly wind direction. When the wind direction shifted, the placement of the Reattachment Zone also shifted.

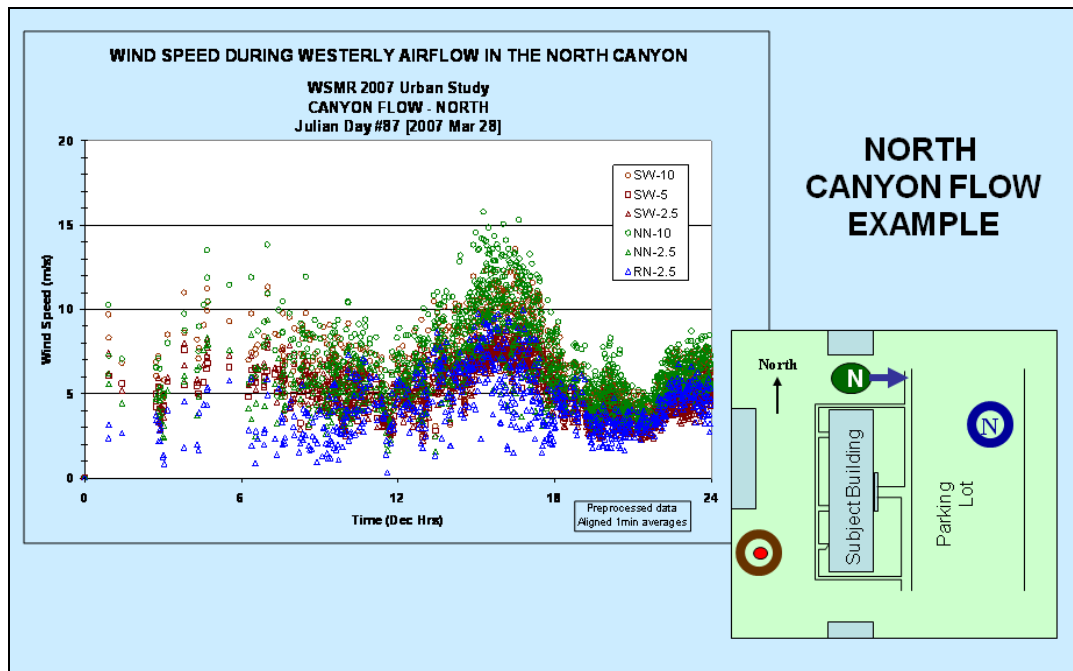


Figure 4. The North-Canyon Flow Schematic on the right shows the Fetch Tower (brown data), North Canyon Tower (green data) and North-Reattachment Zone (blue data) locations. The *W07US* Wind Speed time series on the left shows the relative velocity magnitude changes.

Figure 5 shows an example that elaborates on the wind shift impacts. Once again, we’re looking at a canyon flow scenario. The air flows from the Fetch Tower (brown data and circle), through the southern canyon (green data and circle) and onto the South-Reattachment Zone (blue data and circle). Looking at the coincident time series for each sampling location, from 0000–1000 Local Time (LT), the previous pattern is observed. That is, the Fetch and South-Reattachment Zone data are similar in magnitudes, while the south canyon flow shows higher velocities. However, from 1200–2400 LT, the pre-building wind direction shifted. The resulting wind speeds show an excellent example of the expected stronger velocities going through the canyon. However, the South-Reattachment Zone is no longer supporting the same velocities as the Fetch. In fact, the slower velocities indicate that the perimeter of the building wake effects has shifted to include that sampling site. This implies a much greater potential for higher concentrations of any CB agent trapped at that sampling site.

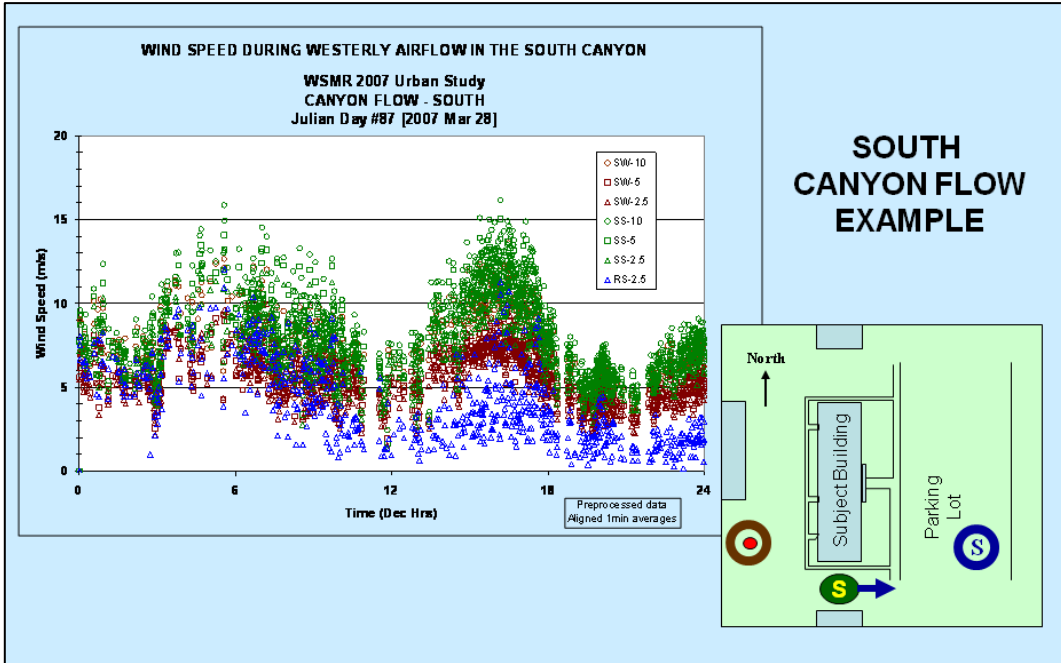


Figure 5. The South-Canyon Flow Schematic right shows the Fetch Tower (brown data), South Canyon Tower (green data) and South-Reattachment Zone (blue data) locations. The *W07US* Wind Speed time series is on the left. From 0000–1000 LT, the Fetch Tower and South-Reattachment Zone are equivalent magnitudes, while the canyon flow is an accelerated flow. From 1200–2400 LT, the south canyon data shows a strong acceleration with respect to the Fetch Tower data.

Figure 6 shows a model simulation of building wakes. A further example of leeside and wake effects will be given in the next two sections. High resolution urban models are continually improving the simulation of building wake footprints as a function of wind direction shifts.

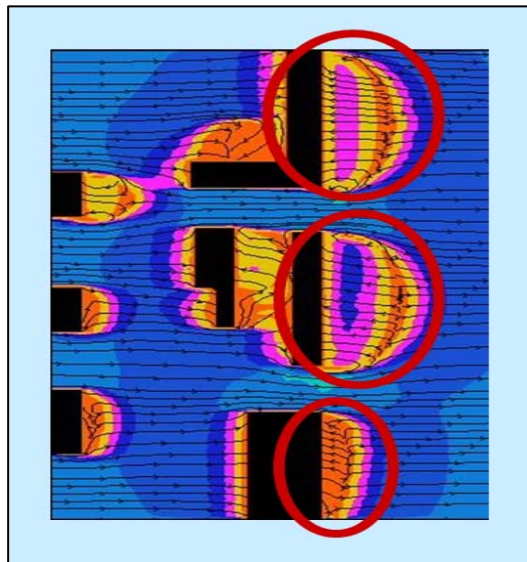


Figure 6. The red circles highlight building wakes generated by 3DWF. Air flows left to right.

2.2 Leeside Corner Eddies

Leeside corner eddies occur on the downwind or leeside of a subject building and are situated within the wake of the building. As is characteristic of all leeside features within the building wake, the overall air velocities are reduced with respect to the general flow around the building. For the person wanting to avoid airborne toxins, the slower airflow implies a potentially sluggish and harmful dispersion of airborne constituents. To complicate matters further, the leeside corner eddy tends to bring the air toward (versus away from) the building.

A north-leeside corner eddy was simulated with arrows in figure 3. This pattern is reiterated on both a north and south leeside building corner in figure 7. The airflow prior to all three eddy examples was a west-to-east moving canyon flow. As the air exited the canyon and entered the lee side of the building, the flow split. A portion of the air was pulled into an upward, vertical spiral, or “eddy”. The remainder of the flow continued independently eastward into a Reattachment Zone. Leeside corner eddies vary in size as a function of local morphology and source flow velocities. The data plotted in figure 7 show those times in which winds were spiraling upward within the dimension of the tower booms and sensors.

Using smoke and other natural airborne tracers, we observed that without trees growing on the building corners, the leeside corner eddies can be much larger than the tower boom lengths in diameter (Vaucher et al., 2008). However, the net effect regarding the eddy characteristics remained the same. The air within the wake of the building tended to support a sluggish environment. Within what movement there was, the airflow path taken brought the air toward the building. Thus CB agents caught within the building’s wake would not necessarily exit the area rapidly.

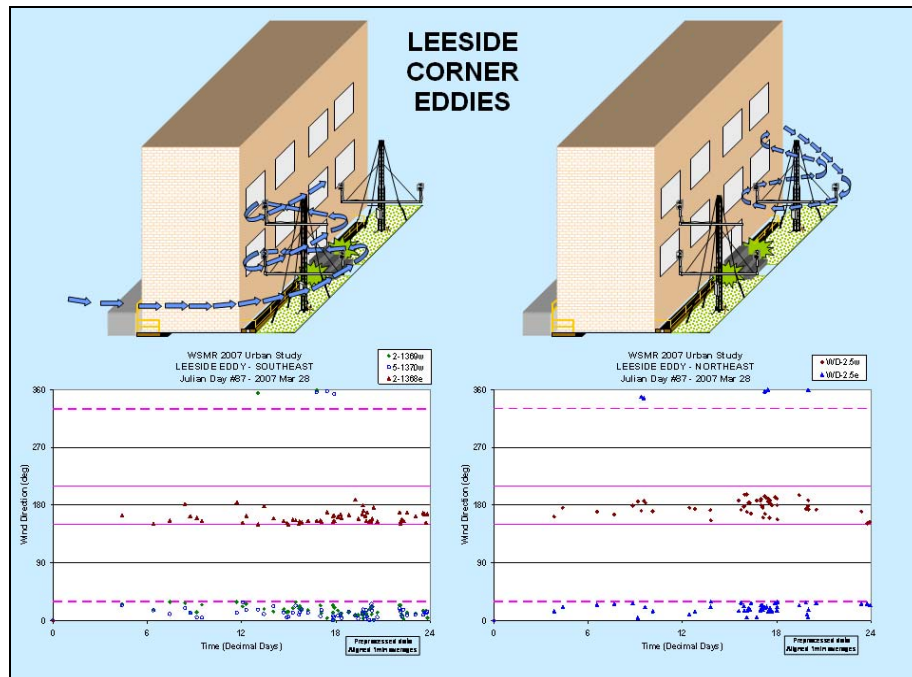


Figure 7. Leeside corner eddies.

2.3 The Leaside Cavity Flow

The “Cavity Flow” or “Flow Reversal” is a leaside pattern located within a building’s wake. The pattern’s velocities are characteristically slower than the surrounding airflow. A typical airflow sequence involving the Cavity Flow might begin with accelerated air flowing over the roof. Immediately after the downwind roof edge, the air velocity would be reduced. Finally, a Cavity Flow pattern would manifest. This series of airflow activity is shown in figure 8, where the upper level flow runs from the west (left of the schematic) to the east.

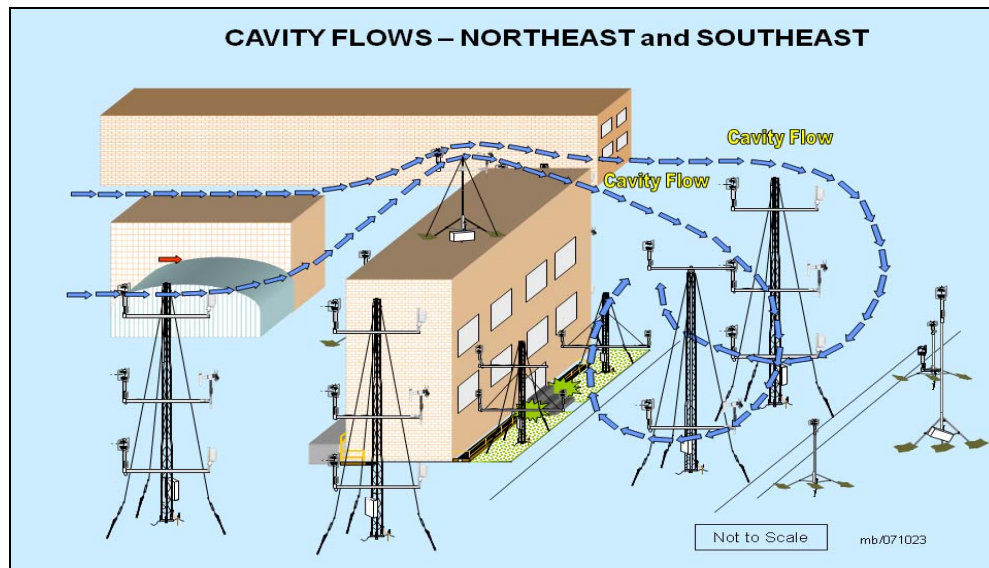


Figure 8. Cavity flow or flow reversal schematic.

As the air descends, the flow reverses. Thus, the near surface flow is east to west. Despite the slower air velocities, the feature still maintains a well-defined reversal in direction, carrying air and all that the air supports toward the structure.

Figures 9 and 10 show data sampled from two independent leaside towers that verify the presence of the Cavity Flow. The coincident upper level (blue data) and lower levels (brown data) center around 270° and 90° , respectively. In figure 9, the “Southeast Tower” recorded a large number of cavity flow cases from mid-day to mid-night LT.

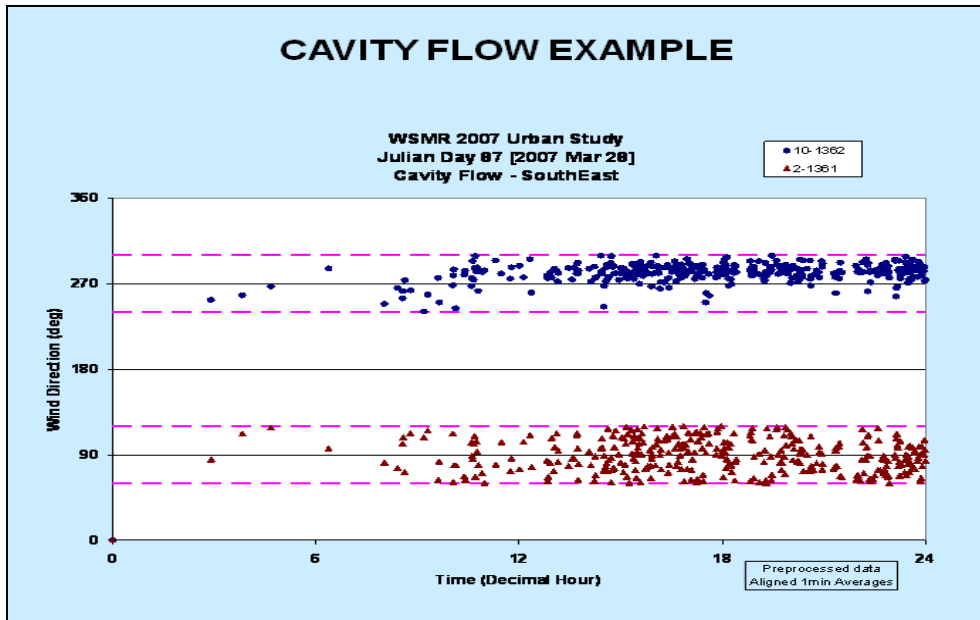


Figure 9. Cavity Flow-Southeast Tower data show coincident winds aloft from the west (blue) and winds near the ground from the east (brown).

Over the same 24 hr period, the “Northeast Tower”, which was spatial only meters away from the “Southeast Tower”, reported a greater cavity flow occurrence during the morning hours. The Northeast Tower (figure 10) includes a mid-level wind sensor which confirms the expected light and variable winds that were present at 5 m above ground level (AGL), while the cavity flow pattern was formed.

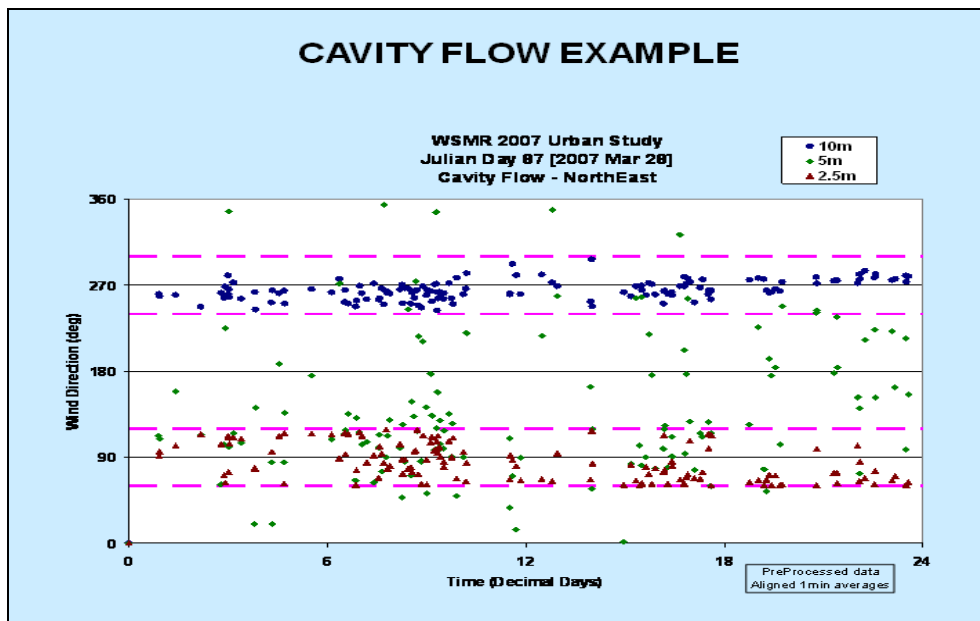


Figure 10. Cavity Flow-Northeast Tower data show coincident winds aloft from the west (blue) and winds near the ground from the east (brown). The mid-level winds (green) are characteristically light and variable.

There are several reasons why this cavity flow pattern is a concern for first persons responding to an airborne release. First, there is a potential for stagnant air within the wake of the building, and second, the systematic direction is toward the building. If a building front door is on the leeward side in the center, the front door may not be the optimal exit for an evacuation.

It is imperative that the person(s) initially responding to an emergency know the best options available. Having the most current atmospheric information is critical in any onsite safety decision making process. Thus, one of the most valued attributes of the L-REAC system will be the quick response interval for collecting, evaluating, and displaying the atmospheric conditions in a given urban environment.

3. Summary

The L-REAC system is a 24/7 atmospheric monitoring, evaluation and display system that is currently being engineered into a prototype by ARL. The L-REAC system design consists of three modules: sensor, model and public communication modules. The concept originated from ARL's urban field studies and will be demonstrated within ARL during FY09. For more information, contact: Ms. Gail Vaucher, Principle Investigator, or Dr. Donald Hoock, Chief, Atmospheric Dynamics Branch through the branch office at (575) 678-1222.

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